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Short Communication

Biomonitoring with bryophytes in managed forested areas. Three examples from the southern Italian Apennines

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Abstract

Three sites in the southern Italian Apennines were selected to assess correlation between forest structure and bryophyte flora. In two of the sites, the Index of Air Purity (IAP)–based on cover data of epiphytic bryophytes–was evaluated. The results show that bryophyte populations–and consequently IAP–are affected by forest structure and development, and that studies including different sites require a precise assessment of silvicultural characteristics to allow comparisons. Indicator values of mosses and liverworts were also taken into consideration in characterizing ecologically the three sites.

Key words: Bryophyte Flora, forest structure, IAP, indicator values, silviculture

Introduction

Bryophytes are a popular tool for the assessment of air quality in polluted urban areas, showing, together with lichens, all the necessary characteristics for a good bioindicator. They are sensible to polluting agents, stay in place in the area of study, have wide distribution and a life cycle sufficiently long, and they can accumulate pollutants in their body (Aleffi 1998; Govindapyari et al. 2010). De Sloover proposed in 1964 an Index of Atmospheric Purity (IAP) to assess air pollution and based on cover data of epiphytic lichens (De Sloover 1964; De Sloover and LeBlanc 1968) and epiphytic bryophytes (LeBlanc and De Sloover 1970). The IAP is extensively applied in cities and urban areas (*e.g.*, Aleffi 1992; Dymytrova 2009; Zechmeister and Hohenwallner 2006) to supplement static and mobile monitors (for CO, CO_2, SO_2, O_3, NO_x), or satellite monitoring systems to assess particulate matter pollution, ground-level ozone, carbon monoxide and other major contaminants in wider areas. The limit of these monitoring devices is that they do not give information about the effects of air contaminants at the ecological level. The aim of this study is to verify the use of the IAP method (selected because of its widespread use and the possibility to have comparable results) in the assessment of environmental pollution in managed forested environments. Cryptogamic communities are conditioned by the developmental stage of the forest (Barkman 1958), and bryophytes, in particular, are important ecological components of managed forests. Bryophyte flora and vegetation provide information on the conditions of a forested area, its structure, ecology and climate at a given time

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(Brunialti et al. 2010). To further characterize ecologically the areas under study, and to evaluate the effectiveness of the Indicator Values of Mosses and Liverworts (Düll 1991), non-epiphytic bryophyte species have been considered. These indicator values were originally developed for Central Europe, but they appear to be usable also in internal mountain areas of southern Italy. The numerical values of these ecological indicators (varying from 1 to 9) are: Light number (L), from deep shade plants to full light plants. Temperature number (T), from cold to extreme warm indicators (from alpine to lowland, or from the Arctic to the Mediterranean zone). Continentality number (C), from euoceanic to eucontinental (from the Atlantic coast to the interior of Eurasia). Moisture number (M), from great dryness to permanently wet or sprayed, near waters or waterfalls, in water). Reaction number (R), from strong acid to base and lime indicators. The Median value is then calculated. Chorological values were also considered, but are not presented here.

Material and methods

The study sites were analyzed by determining their flora (bryological and vascular), climate, geology, pedology. Plots were established and silvicultural parameters calculated (tree-structure and developmental stage).

The IAP (sites A and B) was calculated according to the method presented by LeBlanc and De Sloover (1970) as partially modified by Nimis (1990). In particular, (1) a 60 x 50 cm grid–divided into 20 units of 10 x 15 cm–was placed on the trunk of each tree at a height (lower side) of 80–100 cm, in areas with the highest bryophyte density; (2) The IAP was calculated based on the following formula:

$$\mathrm{IAP} = \sum_{i=1}^{n} (\mathrm{Q}i \times fi / 10),$$

where f_i is an index of frequency/cover varying from 1 to 5; Q_i is the number of species accompanying any other species in each relevée (a factor of resistance to pollution).

The division by 10 is arbitrary and was indicated in the original formula by LeBlanc and De Sloover (1970) to obtain smaller numbers. These values are based on the diversity of epiphytic bryophyte populations, on the resistance to pollution of each species, on the phorophytes, and, in our case, on the forest structure and stage of development. Values of IAP recorded in the literature in urban areas vary according to the distance from the pollution source and the ecological conditions of the site (Nimis 1999). Values may vary from close to zero (indicating air pollution) up to values of 50 or more (indicating lack of air pollution).

The bryophyte vegetation was considered in three sites: (Site A) a managed forested area with *Quercus cerris* L. (Turkey oak) prevalent, and *Quercus pubescens* Willd. (Downey oak) sporadic, near an Oil hub; (Site B) a forested area with *Fagus sylvatica* L. (Beech). The IAP was determined in both sites; (Site C) a mountain area with a *Fagus sylvatica*-*Abies alba* Mill. (Beech-Silver fir) coenosis. The Indicator Values of mosses and liverworts were calculated for all three sites.

Site A

The area of study is situated in a plain near the Oil Hub of Viggiano (Locality Refesa, Province of Potenza, Basilicata) in the Valley of the river Agri at an altitude of

610–620 m, in the heart of the southern Apennines. The geology is complex, in the area considered there is limestone, shale, flysch, and varicolored clay. The soil is various–of alluvial origin under the plots. Climate is Mediterranean with dry summers and the rains occurring mainly from October to February (max. in November, 87.3 mm). Average annual temperature is 12.4 °C. Coldest month average 4.5 °C. Warmer month average 21.6 °C. The De Martonne Aridity Index was calculated, its value (24.3) indicating a sub-humid climate. Overall, a Mediterranean climate of the sub-humid type. According to a recent vegetation classification of Italy this area is included in the temperate region, meso-temperate zone, southern Apennines, neutro-subacidophilous series of Turkey oak (Di Pietro et al. 2010).

Three plots were selected and the usual dendrometry parameters measured (height, dbh, growth estimate, basal area, etc.). The wood is relatively young and the prevalent species is Turkey oak, with the sporadic presence of Downey oak. Sampling occurred in 2003 and then again in 2008. In the first plot the management is simple coppice (low forest) with an average age of 13–14 years (in 2003, 18–19 in 2008). The second plot is inwards with older trees (about 30 years, then 35) and represent an aged coppice in conversion into high forest. The third plot is a coppice-with standards stand, with larger diameters and more spaced trees.

Site B

Mount Paratiello is situated to the west of the town of Muro Lucano (Province of Potenza, Basilicata), in the southern Apennines, in the basin of torrents–some with a more or less continuous flow of water, others with seasonal regimes–tributary to the river Sele. The altitudes vary from 500 to 1400 m. Prevalent expositions N, NE, NW. Geologically young, the erosion has exposed limestone from the Cretaceous. Soils belong to the southern brown earths. The climate is Mediterranean with dry summers and rains occurring mainly from September to March (max. in December, 163 mm). Average annual temperature is 14.3 °C. Coldest month average 2.2 °C. Warmer month average 30.4 °C (data 2000–2010). The Aridity Index of De Martonne is 46.8 indicating a humid climate. According to a recent vegetation classification of Italy this area is included in the temperate region, lower supra-temperate zone, southern Apennines, neutro-basiphilous series of beech (Di Pietro et al. 2010).

The main species in the plots is *Fagus sylvatica* (beech). The forest is quite old and was exploited heavily in the past (1700–1860). Some studies (e.g., Susmel 1957) concluded it should be managed to get an uneven-aged structure, but it has always been managed as an even-aged system. Two plots were selected, at 1356 m, and at 1423 m. The main difference between the two plots is the time of last cutting, more recent in the first one (trees with smaller diameters). Another factor affecting the plots is the slope, steeper at 1424 m–at the tree vegetational limit, and more subject to erosion.

Site C

The population of silver fir on the northern slopes of Mount Motola (Teggiano, Province of Salerno, Campania) represents the most important relict association of silver fir in Campania, where it is associated with the beech. It is included in

the National Park of Cilento and Vallo di Diano, one of the largest in Italy. The habitat belongs to the group of Mediterranean deciduous forests: "Apennine beech forests with *Abies alba*". At lower altitudes (800 to 900 m) *Corylus avellana* L. (Hazelnut) is found in areas previously cultivated. The slopes show a series of terraces supported by stone-walls, eroded by flowing rainwaters. At around 1000 m sparse and isolated individuals of silver fir are found, mostly in hollows and in areas of difficult access. The hazelnut stands still maintain the original density of plantation and the stools feature a high number of shoots, which form a dense and continuous cover not colonized by other species. This area (in the submontane belt up to about an altitude of 800–900 m) belongs to the mixed forest of mesophile and meso-xerophile broadleaf trees (e.g., Pignatti et al. 2004) made up by maples (*Acer campestre* L., *Acer opalus* Mill. subsp. *obtusatum* (Waldst. & Kit. ex Willd.) Gams, *Acer lobelii* Ten.), European hop hornbeam (*Ostrya carpinifolia* Scop.), Chestnut (*Castanea sativa* Miller), Italian alder (*Alnus cordata* (Loisel.) Desf.), Bigleaf linden (*Tilia platyphyllos* Scop.). Climate is cold-humid, Temperate Oceanic, without noticeable temperature extremes. Rains are well distributed during the year. Soils are well aerated brown earths, with an abundant litter layer and good water retention. Geologically limestone prevails (Saracino et al. 2005; Cipollaro and Colacino 2005). According to a recent vegetation classification of Italy this area is included in the temperate region, lower supra-temperate zone, southern Apennines, neutro-basiphilous series of beech (Filesi et al. 2010).

Results

The main silvicultural and bryological (Indicator Values) results are presented for each of the areas considered. (Plots have a diameter of 20 m, and are located at a distance of 60 m one from the other.)

P=Plot; TBA=Total Basal Area (m^2); ABA=Average Basal Area (m^2); AD Average Diameter (cm, min.-max). IAP=Index of Air Purity (Sites A and B only).

Site A – *Quercus cerris* (Turkey oak)

Year 2003:

- P1: #trees 402 – TBA 1.873 – ABA 0.005 – AD 8 (03–21) – IAP=0.32
- P2: #trees 278 – TBA 2.581 – ABA 0.009 – AD 11 (03–36) – IAP=0.43
- P3: #trees 143 – TBA 2.568 – ABA 0.018 – AD 15 (06–31) – IAP=0.37

Year 2008:

- P1: #trees 422 – TBA 3.597 – ABA 0.008 – AD 10.5 (05–19.0) – IAP=1.10
- P2: #trees 243 – TBA 4.120 – ABA 0.023 – AD 14.5 (05–37.0) – IAP=0.80
- P3: #trees 167 – TBA 3.909 – ABA 0.018 – AD 17.0 (05–37.0) – IAP=0.70
- P4: #trees 364 – TBA 1.962 – ABA 0.005 – AD 8.0 (05–23.5) – IPA= NC

Indicator Values of mosses and liverworts:

- L = 7 (Semi-light plants, in full indirect light, but also occurring in shade). T = 4 (between moderate warm and cool). C = 5 (Intermediate, between

sub-Mediterranean and sub-boreal). M = 4 (places moderately fresh becoming dry for long periods). R = 6 (between moderate acid and weakly acid to weakly basic indicator).

Site B – *Fagus sylvatica* (Beech)

- P1 1356 m: #trees 288 – TBA 4.635 – ABA 0.016 – AD 14.5 (5–69) – IAP=2.2
- P2 1423 m: #trees 152 – TBA 6.601 – ABA 0.043 – AD 23.0 (5–60) – IAP=4.0

Indicator Values of mosses and liverworts:

- L = 7 (Semi-light plants, in full indirect light, but also occurring in shade). T = 3 (cool). C = 5 (Intermediate, between sub-Mediterranean and sub-boreal). M = 4 (places moderately fresh becoming dry for long periods). R = 6 (between moderate acid and weakly acid to weakly basic indicator).

Site C – *Fagus sylvatica-Abies alba* (Beech-Silver fir) coenosis

- P1 900 m: #trees 438 – TBA 18,4 – ABA 0.042 – AD 23.1 (Beech)
- P1 900 m: #trees 275 – TBA 18,5 – ABA 0.067 – AD 29.3 (Silver fir)
  - Sporadic presence of Bigleaf linden, Hungarian maple and Chestnut: TBA 3.75.
- P2 1100 m: #trees 703 – TBA 30.2 – ABA 0.043 – AD 23.4 5 (Beech)
  - Sporadic presence of European hop hornbeam, Hungarian maple and Italian alder. Silver fir (sub-canopy) TBA 2.5.

Indicator Values of mosses and liverworts:

- 700–900 m: L = 5 (semi shade plants), T = 5 (moderate warmth), C=5 (intermediate), M = 7 (moisture), R =7 (weakly acid to weakly basic).
- 1000–1300 m: L = 5 (as above), T = 4 (sub-Oceanic), C = 5 (as above), M = 7 (as above), R = 6 (between moderate acid and weakly acid to weakly basic).

In this site the study has been focused on the bryophyte flora and the silvicultural aspects, from lower to higher altitudes. No IAP was calculated.

Discussion

Site A – The silvicultural data show there has been, as expected, an increase in the average diameters in the three plots after 5 years, which is reflected also in the values of total and average basal areas. This increase in diameter has affected the number of epiphytic bryophyte species recorded. Downey oak was not considered in the measurements, being a much better phorophyte. Plot 4 of 2008 was made up of very young plants with smaller diameters, too small to have any significant epiphytic vegetation. IAP could not be calculated (NC). Overall, TBA values appear low, indicating a forest in the first stages of development. The Indicator values of mosses and liverworts–re-

flecting the general ecological conditions of the site–have not changed from 2003 to 2008, as expected.

Site B – Plot 1 was cut more recently than Plot 2, as indicated, altering the number of epiphytes capable to attach and grow on the bark, and resulting in different IAP values. These values, in both plots, are quite low, not much different from those obtained in Site A which was exposed to pollution. This may be due to the type of forest management applied, with younger trees prevailing, and lacking the time to reach an equilibrium (as shown by low TBA values). The Indicator values appear to be almost identical in the two plots. Plot 1 has the same values, while Plot 2 diverges only for M = 3 (dryness); this is due to its position near the tree line and the uppermost montane grassland (edge effect) exposing to the sun the bryophytes from the inside, as it was shown by Hylander (2005).

Site C – This forest is characterized by silver firs. Beeches become more frequent in the higher parts of the submontane belt, as compared to other broadleaf trees (Plot 1). In this belt, the presence of all diametrical classes of silver firs in reproductive age has been recorded (an abundant production of cones was observed during Fall 2002). Silver firs here are taller than beeches, and their canopy is directly exposed to sun rays. Their spatial distribution varies from isolated plants within a stand of beeches, to pure populations with an extension of even a few thousand square meters exhibiting the micro-environmental conditions of pure silver fir forests. At higher altitudes (Plot 2) beeches become the dominant trees and silver firs almost disappear (even though old big stumps and rotting logs are still visible). Silver firs are still relatively abundant in the sub-canopy layers as individuals of about 1–4 m of height in a "waiting" phase, many with the vegetative apex damaged by grazing or by contact with branches of higher trees. The Indicator values show that bryophytes of xeric or Mediterranean environments prevail at lower elevations, while at higher elevations, at the tree line, species with a sub-Oceanic (and sub-Mediterranean) ecology prevail, as expected given the different ecological conditions previously indicated.

Conclusions

The values of IAP obtained in this study need consideration, and an explanation. These values are lower in Site A, near a source of pollution, and higher in site B, with no apparent pollution source, as expected. The IAP values in site B, however, are much lower than those normally obtained in unpolluted urban areas. This may be related to the silvicultural management systems applied, with frequent cutting of trees and resulting low TBAs, altering adversely bryophyte diversity because of their vulnerability to microclimatic changes (Perhans et al. 2009). Further study is required to compare IAP values from forest sites to those obtained in urban areas; the determination of correction factors (possibly based on TBA values, and phorophyte selection) is necessary. A preliminary strategy–limited to forested areas, would be to consider stands at the same stage of development and with comparable management systems, better if aged (Hébrard 1989). The effectiveness of the Indicator values for mosses and liverworts for the areas considered was verified both spatially (sites A, B, and C) and temporally (site A).

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

The author solely contributed to this work.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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